BULLETIN 324 NOVEMBER 1945

Pasture Fertilization Experiments

at

Reymann Memorial Farm

by

F. W. Schaller, G. G. Pohlman, H. O. Henderson, and R. A. Ackerman

Agricultural Experiment Station
College of Agriculture, Forestry, and Home Economics
West Virginia University
C. R. Orton, Director
Morgantown

THE AGRICULTURAL EXPERIMENT STATION STAFF

C. T. NEFF, Jr., A. B., Acting President of the University
C. R. ORTON, Ph. D., Sc. D. .... Dean and Director
F. D. CORNELL, Jr., Ph. D. .... Assistant Director
JOHN C. JOHNSTON, Assistant to Director .... GERALD JENNY, M. S., Editor

AGRONOMY AND GENETICS

G. G. Pohlman, Ph. D., Agronomist
W. M. Broadfoot, M. S.,(1) Asst. in Agron.
D. R. Browning, M. A.,(2) Asst. in Agron.
J. L. Cartledge, Ph. D., Assoc. Gen.
S. L. Galpin, Ph. D., Hydrologist
T. C. McIlvaine, Ph. D.,(3) Assoc. Agron.
F. W. Schaller, M. S.,(1) Asst. in Agron.
E. H. Tyner, Ph. D., Assoc. Agron.

ANIMAL HUSBANDRY

E. A. Livesay, D. Sc., An. Husbandman
R. H. Black, M. S.,(1) Asst. in An. Husb.
T. B. Clark, M. S., Assoc. Poult. Husb.
H. M. Hyre, M. S., Assoc. Poult. Husb.
M. A. McHale, D. V. M., Asst. An. Path.
Helen M. Pavlech, B. S. Ed., Asst. in An. Husb.
J. H. Rietz, D. V. M., An. Path.
T. D. Runnels, M. S.(1) Asst. in Poult. Husb.
B. H. Schneider, Ph. D., An. Husb.

CHEMISTRY

R. B. Dustman, Ph. D., Agr. Chem.
C. A. Flanders, M. A., Asst. Chem.
Paul Lyon, Tech. Aid
A. H. VanLandingham, Ph. D., Assoc. Chem.
C. E. Weakley, Jr., M. A., Assoc. Chem.

DAIRY HUSBANDRY

H. O. Henderson, Ph. D., Dairy Husbandman
W. J. Tyler, Ph. D., Asst. in Dairy Husb.
S. J. Weese, M. A., Asst. Dairy Husb.

ECONOMICS (AGR.)

W. W. Armentrout, Ph. D., Agricultural Economist
R. H.. Bradford, M. A.,(1) Assoc. Rural Sociol.

ENTOMOLOGY

L. M. Peairs, Ph. D., Entomologist

FORESTRY

W. C. Percival, Ph. D., Forester
F. W. Besley, Sc. D., Assoc. For.
Lowell Besley, M. F.,(1) Assoc. For.
M. G. Brooks, M. S., Assoc. For.
J. B. Byers, B. S.,(1) Asst. in For.
R. F. Dugan, M. F., Asst. For.
H. D. Erickson, Ph. D., Assoc. For.
Torkel Holsoe, M. F.,(1) Asst. For.
A. S. Margolin, Ph. D., Asst. Pillculturist
E. H. Tryon, Ph. D., Asst. For.

HORTICULTURE

R. S. Marsh, M. A., (7) Horticulturist
W. H. Childs, Ph. D., Assoc. Hort.
J. D. Downes, B. S. Agr., (1) Asst. in Hort.
A. P. Dye, M. S., Asst. Hort.
O. M. Neal, Jr., B. S.,(1) Asst. in Hort.
R. H. Sudds, Ph. D., Assoc. Hort.
K. C. Westover, Ph. D., Hort.

PLANT PATHOLOGY AND BACTERIOLOGY

J. G. Leach, Ph. D., Plant Pathologist
H. L. Barnett, Ph. D., Assoc. Mycol.
Anthony Berg, M. S., Assoc. Plant Path.
Genevieve B. Clulo, M. A., Asst. Plant Path.
A. R. Colmer, Ph. D., Assoc. Bact.
V. G. Lilly, Ph. D., Assoc. Physiol.
C. F. Taylor, Ph. D., Assoc. Plant Path.

MISCELLANEOUS

R. A. Ackerman, M. S.,(4) Asst. Dairy Husb.
C. J. Cunningham, B. S. Agr.,(5) Asst. An. Husb.
Edwin Gould, B. S.,(6) Assoc. Entomol.
W. M. Nelson, A. R. P. S., Photog.
H. E. Pease, A. B., Asst. Ed.

(1) On leave for military service.
(2) In cooperation with the United States Department of Agriculture.
(3) In charge of the Lakin Experiment Farm.
(4) In charge of the Reedsville Experiment Farm, Reedsville, West Va.
(5) In charge of the Reymann Memorial Farms, Wardensville, West Va.
(6) In charge of the University Experiment Farm, Kearneysville, West Va.
(7) On leave of absence

Pasture Fertilization Experiments

at

Reymann Memorial Farm

by F. W. Schaller, G. G. Pohlman, H. O. Henderson, and R. A. Ackerman

BECAUSE OF THE ROUGH topography of much of the land in the state, a large acreage of farm land must be devoted to pasture if it is to be utilized for agriculture without causing excessive erosion. Since pastures furnish the cheapest livestock feed produced on the farm, the improvement of pastures and the maintenance of their fertility and carrying capacity are vital to West Virginia agriculture.

Numerous trials have demonstrated the value of lime and superphosphate as a means of establishing and maintaining productive pastures in West Virginia (8).* Most of these trials have been conducted in small plots which have been clipped with a lawnmower because of the high cost of extensive grazing tests.

The investigation from which this report is taken was carried out with grazing dairy animals and was designed to determine the effect of fertilizer treatments on the yield of pastures as measured by the animal units carried.

This study was carried on at the Reymann Memorial Farm at Wardensville, West Virginia, during the years 1931 to 1941, inclusive.

EXPERIMENTAL PASTURES

DESCRIPTION OF AREA

The diagram of the experimental area given in Figure 1 shows the general lay-out and fertilizer treatment. The area, consisting of 39 acres, was rectangular in shape. This was divided into eight long narrow plots or pastures, and each pasture extended across the area in an east-west direction. The treatments included (1) check or untreated, (2) lime and superphosphate, (3) lime, superphosphate, and potash, and (4) lime, superphosphate, potash, and nitrogen. All treatments were in duplicate. In order to compensate partially for differences in carrying capacity, the check or untreated pastures consisted of six acres each, as compared with 4½ acres for the treated pastures.

The land surface was level to gently rolling. The soil type was principally Monongahela fine sandy loam, which is a strongly leached terrace soil derived from non-calcareous sandstone and shale sediments. Though naturally low in productivity, it is known to produce good crops if limed, fertilized, and properly managed. The surface layer was approximately 8 inches deep with a subsoil (B horizon) varying in depth from 2 to 4 feet. Chemical analysis of the surface 3 inches, before

*Figures in parenthesis refer to "Literature Cited," p. 24.

treatment, showed an average pH value of about 5.0 and an available phosphorus content of 12 pounds per acre as determined by the Truog method (*10*).

PREVIOUS LAND USE

The west half of the area had been in permanent pasture before 1931, whereas the east half had been in various cultivated crops. So far as is known, no lime or fertilizer had been applied before the experiment other than some barnyard manure in the cropped section. Some difference in fertility between the two sections was evident throughout the experiment.

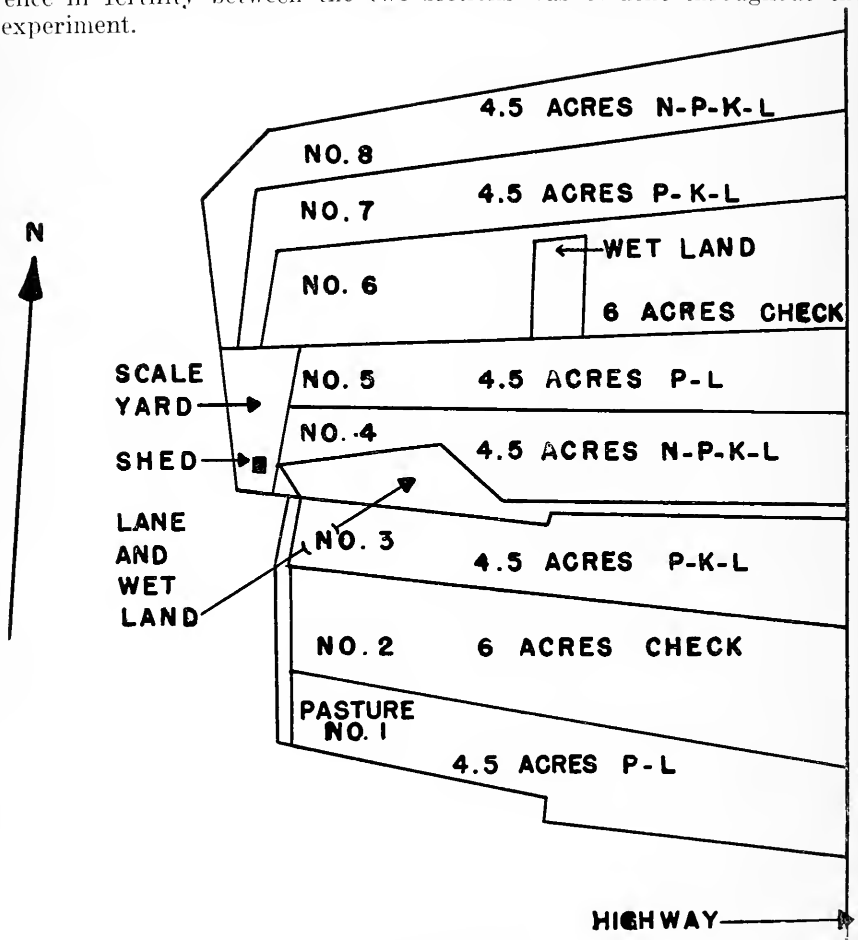

FIGURE 1—Experimental Grazing Plots at Wardensville, West Virginia

TREATMENTS

L = Ground limestone sufficient to bring soil to pH 6.5.

P = 500 lbs. per acre of 20 percent superphosphate in 1931 and 1933.

K = 100 lbs. per acre of muriate of potash in 1931 and 1933.

N = 1931 to 1936, 200 lbs. per acre of nitrate of soda in two equal applications,, one in early April and the other about July 1, 1936, to 1941, 100 lbs. per acre of nitrate of soda applied in early April.

PASTURE TREATMENT

SEEDING

Early in April 1931 the area was plowed and prepared for seeding. The land was double-disked twice and harrowed sufficiently to give a smooth, compact seedbed. All seedings were made before the plots were fenced into their respective pastures in order that uniform seeding might be secured. The seed was sown broadcast, one-half lengthwise and one-half crosswise of the field to insure uniform distribution, and covered with a spike-toothed harrow.

A very simple seed mixture was used; although not recommended for ordinary farm practices, for experimental purposes it seemed advisable, since it is the type of vegetation which ultimately persists in most improved West Virginia permanent pastures. The mixture consisted of Kentucky bluegrass, redtop, and white clover. Oats were used as a companion crop. These were harvested for hay in June. Weeds were cut later in the season. The pastures were not grazed in 1931.

LIME AND FERTILIZER USED

The initial application of lime and fertilizer was applied with a drill in April 1931 just after plowing and was worked into the soil before seeding. Limestone was applied in an amount calculated to bring the surface 3 inches of soil to a pH of 6.5. The actual amount applied was 2,950 pounds per acre of pulverized limestone with a calcium carbonate equivalent of 80 percent. The phosphate treatment consisted of 500 pounds per acre of 20 percent superphosphate, and the potash treatment was 100 pounds per acre of muriate of potash. A subsequent application of 500 pounds of 20 percent superphosphate and 100 pounds of muriate of potash was broadcast on the surface in April 1933.

During the period 1931 to 1936, inclusive, the nitrogen treatment consisted of 200 pounds per acre of sodium nitrate applied every year in two equal applications, one in early April and one about the first of July. From 1937 to 1941, inclusive, the nitrogen application was reduced to 100 pounds per acre of sodium nitrate applied in April. All applications were made with a fertilizer drill.

METHODS OF MEASURING RESULTS

ANIMALS USED

During the 1932 season the pastures were grazed with milking Ayrshire cows. From 1933 to 1941, inclusive, Ayrshire heifers were used because the producing cows added many additional variables to the experiment and complicated the supervision and handling of the work. In general the method of grazing and management of the pastures was essentially the same for the two types of animals. However, since milking cows were used during one year only, the discussion will be confined chiefly to the use of the dairy heifers.

The heifers used were mostly yearlings and received no supplementary feed. They were taken off barn feeding in early April and turned into an auxiliary pasture for two weeks before being put on the experimental plots. This gave them ample time to become adjusted to pasture feeding. The auxiliary pasture was similar in character to the untreated pastures and was used also to maintain additional animals for possible use during the season. An effort was made to have the groups of cattle on the eight different pastures as nearly comparable as possible in regard to age, live weight, and stage of gestation. Ordinarily there were three to seven animals on the better pastures and two to four on the poorer ones

Grazing started in the spring as soon as the grasses reached a height of approximately 3 inches and usually continued until about November 1. Animals were put on or taken off the different pastures in such numbers as to insure uniform grazing. An attempt was made to graze to the extent that but little grass would be wasted or grow tall enough to shade white clover. However, clumps of uneaten grass could not be avoided in any of the pastures. It was usually necessary to mow the pastures during the summer to remove the clumps and tall weeds. The cattle were on the pasture continuously except when taken off to be weighed. Water and salt were available on each pasture at all times.

During the 1932 season when the pastures were grazed with Ayrshire cows, the yield of total digestible nutrients supplied by the pastures was calculated by allowing for maintenance, changes in body weight, amount of milk and butterfat produced, and the nutrients supplied by supplementary feed. The total digestible nutrients required for maintenance and for milk and butterfat production were calculated from data given by Morrison (*6*). Allowance for changes in body weight was made in accordance with the recommendations of Knott, Hodgson, and Ellington (*5*).

The yield of total digestible nutrients from grazing with dairy heifers was calculated from the data of Eckles and Gullickson (*3*) for the nutrient requirements of Holstein heifers for maintenance. The nutrients required for gains in weight were calculated from an adaptation of these data by Enlow (*9*).

The weights of the cattle were based on the average of weighings made on two consecutive days. All cattle were weighed before being put on pasture and at approximately monthly intervals thereafter. Additional weighings were made when cattle were added to or removed from a pasture between regular weighing dates.

BOTANICAL COMPOSITION

In order to have a record of the kinds and relative amounts of the various plants making up the pasture sod, botanical estimates were made on nine caged areas (4 by 4 ft.) located at random in each pasture. They were made twice each year, usually during June and September. The percentage of the total area occupied by weeds, native grasses, white clover, Kentucky bluegrass, and redtop as well as the percentage of bare space was recorded.

CHEMICAL ANALYSIS OF HERBAGE

Caged areas were clipped with a lawn mower at a height of approximately 1⅜ inches. Clippings were made on the same dates on which the cattle weights were taken. The clipped herbage was dried, weighed, ground, and analyzed for protein, calcium, phosphorus, and potassium.

Protein and calcium analyses were made according to the method of the Association of Official Agricultural Chemists (*1*). Phosphorus was determined by the method of Fiske and Subbarow (*1*) and potassium by the method of Brown, Robinson, and Browning (*2*).

SOIL ANALYSES

Soil samples were taken with a soil tube and cut into lengths representing the depths 0-1½, 1½-3, and 3-5 inches. pH values were determined with the glass electrode, using a soil ratio of 1:2½. Available phosphate analyses were made according to the method of Truog (*10*). For the analysis of potassium the soil was leached with ammonium acetate and the potassium determined by the method of Brown, Robinson, and Browning (*2*). Results are given only for the 0-1½-inch layer.

CLIMATIC CONDITIONS

In this section of West Virginia the quantity and distribution of rainfall has a pronounced effect on crop yields and especially on pastures. The Weather Bureau normal or average annual rainfall is 30.36 inches. This average is relatively low as compared to most parts of West Virginia. Moisture frequently becomes a limiting factor in production.

Table 1 shows the monthly precipitation for the period 1931 to 1941, inclusive, in comparison with the normal or average rainfall. This, however, does not tell the whole story. Further explanation is necessary.

In 1931 the rainfall, otherwise normal for the year, was 2.86 inches above normal during the growing season, April through October. The greater part of this excess came during July and August, when it is generally most needed. The pastures were seeded in the spring of that year. With the favorable amount and distribution of rainfall, a good stand was obtained.

The seasons 1933, 1935, 1939, and 1940 had above-average rainfall which was well distributed throughout the season, and the pasture gave good yields. In each of the other seasons, dry periods affected total and seasonal production. In 1932 the dry period in July, August, and September reduced growth to such an extent that the heifers had to be removed early in August. Dry weather during the early part of the pasture season reduced yields in 1934. The season of 1936 was dry during most of the pasture season, with the results that no grazing was obtained after July 1. An early dry spell in 1937 reduced growth of pasture grasses to such an extent that the animals were removed August 3. However, heavy rains in August caused growth to start. The animals were returned on September 1, and good grazing was obtained until late October. Dry weather in April and June of 1938 reduced growth, and

TABLE 1—*Precipitation at Wardensville*

Year	April	May	June	July	Aug.	Sept.	Oct.	Total for seven months	Total for twelve months
1931	3.17	3.67	3.16	5.82	5.13	1.90	0.96	23.81	30.90
1932	1.22	6.70	3.55	2.59	1.61	0.98	5.66	22.31	36.16
1933	4.61	6.24	1.90	6.77	7.01	5.36	1.14	33.03	41.89
1934	1.76	2.77	1.73	5.27	4.53	3.53	1.11	20.70	29.67
1935	4.53	2.99	2.58	4.00	3.82	5.03	2.13	25.08	36.61
1936	2.03	1.48	2.78	3.59	2.10	0.68	2.80	16.46	37.01
1937	5.97	1.47	2.20	2.25	14.44	2.57	6.73	35.63	46.87
1938	1.68	5.06	2.15	[illegible]	1.86	2.57	[illegible]	17.36	26.26
1939	2.43	2.71	4.41	6.74	3.38	2.52	2.31	25.50	37.12
1940	5.05	3.56	5.07	3.16	6.31	3.04	1.63	27.82	39.13
1941	1.96	1.83	3.32	6.13	4.57	1.01	0.75	19.57	27.36
Av. 1931-1941	3.07	3.50	2.99	4.51	4.98	2.65	2.59	24.29	35.36
Av. 1917-1931*	2.51	2.96	3.00	3.10	3.63	2.59	3.16	20.95	30.36

*Weather Bureau adjusted mean.

there was little grazing in July. Early grazing was light in 1941 because of low rainfall in April and May, but the remainder of the season was quite favorable.

In general, temperature was normal except for a tendency to be slightly above average during periods of dry weather, especially in 1932, 1934, and 1936.

EXPERIMENTAL RESULTS

EFFECT OF TREATMENT ON SOILS

Soil samples were taken during the course of the experiment to study the effect of treatment on soil properties commonly affecting vegetation in pastures. The analyses of samples taken at the close of the experiment are given in Table 2.

TABLE 2—*Effect of Treatment on Soils* (1942)*

Plot no.	Treatment	pH	Available phosphorus†	Exchangeable potash†	Organic matter
					(*percent*)
2	Check	5.18	17	82	2.11
6	Check	5.42	22	71	2.32
1	P L	5.75	47	1[illegible]4	2.42
5	P L	5.76	62	59	2.73
3	P K L	5.53	27	93	2.53
7	P K L	5.86	40	84	2.41
4	N P K L	5.93	35	65	2.98
8	N P K L	6.15	52	72	2.37

*Results are for the 0-1½ inch layer.
†Expressed as lbs. per 2,000,000 lbs. surface soil.

Although the soil analyses indicate considerable variation between duplicate plots, certain facts are evident. The lime applied shows an appreciable effect on the soil reaction expressed as pH in all the treated pastures, even though the samples were taken 11 years after liming. In all cases the pH values are lower than the value originally sought (pH 6.5). It is probable that there would be response to additional applications of lime. Likewise, the available phosphate content is higher in all the treated pastures, showing that there still remains a considerable residual effect on the supply of phosphorus even after 9 years.

The exchangeable potash values give a measure of the available potash in the soil. Although there is considerable variation in the area, all plots are relatively low. The extremes are represented by the two plots receiving lime and superphosphate, plot 1 being the highest and plot 5 the lowest of any of the plots. It would appear that the relatively high value for plot 1 may account for the good yields on this plot, whereas the low value for plot 5 may be responsible for the low response to lime and phosphate in this area.

The effect of treatment on the organic matter supply is also given in Table 2. These data show that liming and fertilizing has increased the organic matter in the surface layer. The effect was probably due to the change in type and amount of vegetation rather than to a direct effect

of treatment. Regardless of the cause, the increased supply of organic matter would improve the physical and chemical condition of the soil and, as a result, would make the soil a more favorable medium for plant growth.

The variation in the soil as shown by these analyses must be kept in mind in evaluating the effectiveness of the various treatments.

EFFECT OF LIME AND FERTILIZER ON BOTANICAL COMPOSITION

It has been recognized that under West Virginia conditions the carrying capacity or the number of acres required to pasture an animal unit is determined largely by the percentage of desirable species in the pasture (7) (8). If the soil is fertile and the pasture has been well managed, Kentucky bluegrass and white clover are usually the dominant species. Other desirable plants such as redtop, orchard grass, hop clover, and common lespedeza are also frequently present. If the soils are acid and of low fertility, poverty grass, broomsedge, and weeds usually predominate. Pastures consisting mostly of desirable plant species produce not only higher yields but also herbage which is more nutritious and palatable. For these reasons the value of lime and fertilizer on permanent pasture will be determined to a great extent by the effect it has upon the kind of plants present in the pasture.

Since the area in this experiment was plowed and seeded with Kentucky bluegrass, redtop, and white clover, these were the only desirable species present in the pastures. The weeds consisted chiefly of buckhorn plantain, yarrow, oxeye daisy, and field sorrel. The native grasses were mainly broomsedge with lesser amounts of crabgrass, *Panicum, Paspalum, Aristida,* and foxtail.

Kentucky Bluegrass and Redtop

In 1932 and 1933 a combined estimate of Kentucky bluegrass and redtop was made. From 1934 to 1941, separate estimates of each species were made in the early summer of each year. These data are given in Figure 2 and Table 3.

It is evident from Figure 2 that a good stand of grass was obtained on all pastures regardless of treatment. As previously mentioned, the

TABLE 3—*Average Estimated Botanical Composition of Each Pasture During the Period* 1932 *to* 1941

Plot no.	Treatment*	Average 1932-1941: Bare space	Weeds	Native grasses	White clover	Kentucky bluegrass & redtop	Average 1934-1941†: Kentucky bluegrass	Redtop
2	Check	39	12	18	2	29	6	15
6	Check	38	8	9	5	40	29	9
1	P-L	19	8	4	9	60	57	5
5	P-L	30	6	3	4	57	47	9
3	P-K-L	14	7	2	13	65	60	5
7	P-K-L	20	6	2	11	61	57	5
4	N-P-K-L	14	6	2	8	70	65	5
8	N-P-K-L	17	7	2	10	66	64	5

*See Figure 1 for explanation of treatment.

†Individual estimates of Kentucky bluegrass and redtop were not made in 1932 and 1933.

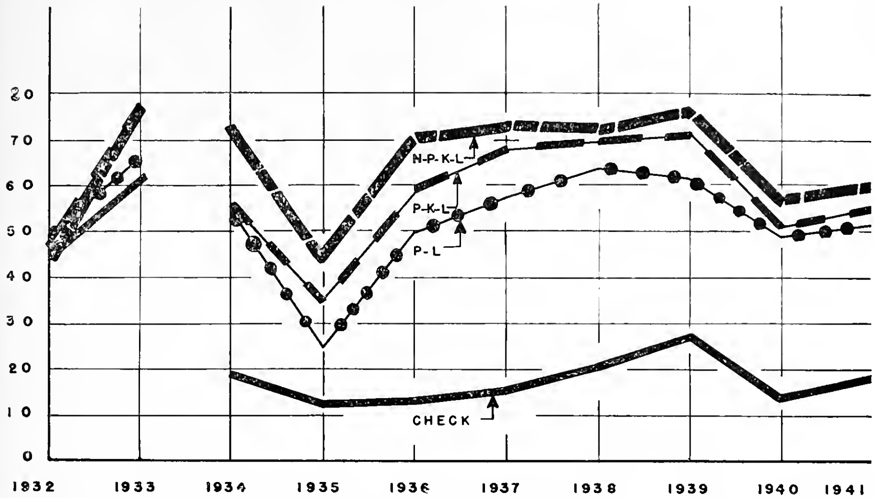

FIGURE 2—The Effect of Lime and Fertilizer on the Annual Percentage of Kentucky Bluegrass

Each value represents the average of two pastures. (See Fig. 1 for explanation of treatments.) The values for 1932 and 1933 include redtop.

year of seeding (1931) was an excellent growing season, and by the spring of 1932 the stand of bluegrass and redtop varied only from 44 percent on the check pastures to 49 percent on the pastures receiving lime and phosphate. Observations revealed that the stand was dominantly redtop but contained many small plants of Kentucky bluegrass. The amounts of bluegrass and redtop increased in 1933, but estimates made in 1934 indicated that by the end of the second season most of the Kentucky bluegrass had succumbed to the high acidity and low fertility of the soils on the untreated pastures. Redtop was somewhat more resistant to these conditions but it, too, largely disappeared by end of the third season. On the treated pasture Kentucky bluegrass soon became the dominant species. Redtop was not able to compete with the vigorous growth of the bluegrass and was gradually crowded out during the next three years until only a trace remained.

The growing season of 1934 was deficient in rainfall, and the stand of grasses declined, with the result that the estimates of 1935 showed the poorest cover during the entire period of the experiment. The rainfall during the season of 1935 was above normal, and the Kentucky bluegrass came back rapidly on all the treated pastures. The stands continued to increase during 1936 but showed little change during the next three years (1937 to 1939). The 1940 and 1941 estimates show considerable reduction in the stand. Although there probably was a tendency for the Kentucky bluegrass to decrease in the latter years, since no fertilizer was applied after 1933, a part of the difference is believed to be due to the time when the estimates were made. In 1939, as well as in the earlier years, the estimates were made in June, when Kentucky bluegrass

is most vigorous, whereas in 1940 and 1941 these estimates were made about mid-July, when Kentucky bluegrass appears less thrifty because of high temperatures and insufficient moisture.

The stand of Kentucky bluegrass on the untreated pastures, after reaching its lowest value in 1935 and 1936, continued to remain low during the remainder of the experiment. Broomsedge and weeds became the dominant species of these pastures.

The data presented in Figure 2 show that the use of lime and superphosphate was essential in maintaining a satisfactory stand of Kentucky bluegrass. It also appears that potash effected a further increase in the stand. However, a study of Table 3 indicates that part of this difference was due to plot variation. The average stand of Kentucky bluegrass on the two pastures receiving lime and superphosphate was 57 and 47 percent, respectively, whereas on the two pastures which received potash in addition, the stand was 60 and 57 percent.

Nitrogen, in addition to lime, superphosphate, and potash, has caused a slight increase in the stand of Kentucky bluegrass. Table 3 shows that the average stand of Kentucky bluegrass from 1934 to 1941 on the two N-P-K-L pastures was 65 and 64 percent as compared with 60 and 57 percent on the P-K-L pastures.

White Clover

The average annual percentages of white clover are plotted in Figure 3. The season of 1931 was favorable to the establishment of white clover, and by the spring of 1932 the percentage stands averaged 25, 20, 44, and 45 percent, respectively, for the check, P-L, P-K-L, and N-P-K-L treatments. From this it is indicated that the original content of bases and

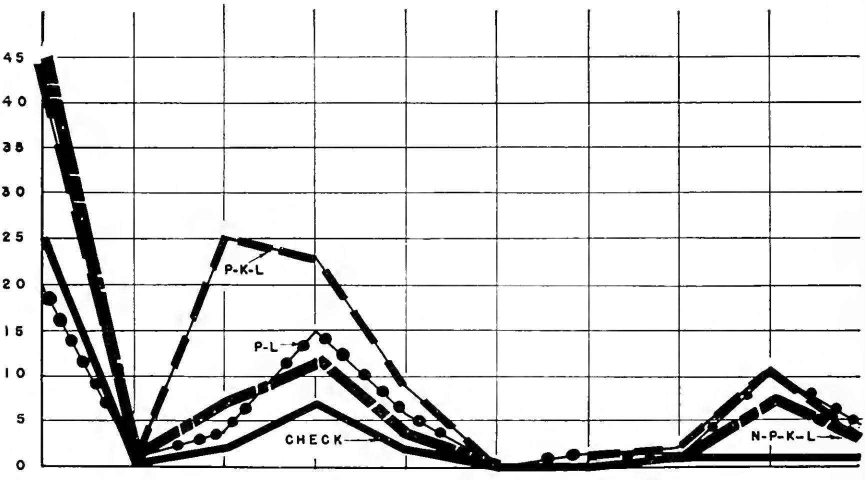

FIGURE 3—The Effect of Lime and Fertilizer on the Annual Percentage of White Clover

Each value represents the average of two pastures. (See Fig. 1 for explanation of treatments.)

available phosphate was sufficient to establish a fair stand of white clover, and little response resulted from applications of lime and superphosphate. Potash, in addition to lime and superphosphate, markedly increased the clover stand, but the use of nitrogen had no effect.

There was little rain during July, August, and September 1932. The white clover almost completely disappeared as shown by estimates made in the spring of 1933.

The second application of superphosphate and potash made in the spring of 1933 brought about an increase in the white clover during the three following seasons, 1933 to 1935. The response to potash during this period was especially marked. Nitrogen depressed the white clover in these years, and the stand on the N-P-K-L pastures was about the same as that on the P-L pastures.

The season of 1935 was very favorable for pasture growth, and Kentucky bluegrass increased very rapidly. This tended to crowd out the white clover and probably was responsible for its decline in that year. In 1936, dry weather and the continued increase in Kentucky bluegrass caused the white clover to disappear almost completely. It did not reappear until 1939, when rainfall was again favorable. By the spring of 1940 the stands of white clover averaged 1, 11, 11, and 8 percent, respectively, on the check, P-L, P-K-L, and N-P-K-L pastures. It appears that nitrogen may have slightly decreased the stand, even though only 100 pounds per acre per year had been used insce 1937.

The estimates in 1941 show that white clover was again declining. Inasmuch as no mineral fertilizers had been applied since 1933, it is believed that additional applications would have been necessary to maintain the white clover.

The effect of lime and fertilizer on the amount of white clover is also evident in the average percentages for the 10-year period of 1932 to 1941, which are given in Table 3.

EFFECT OF LIME AND FERTILIZER ON COMPOSITION OF HERBAGE

Chemical analyses of the pasture herbage during all years of the experiment are not available. However, these which are available are believed to be quite indicative of the effect of lime and fertilizer on the quality of forage which was produced.

The crude protein content of the forage produced during the years 1932 to 1936, as reported in a previous publication (*9*), showed from 12.6 to 15.5 percent protein on the untreated pastures, with an average of 13.7 percent. On the treated pastures the range was from 14.3 to 20.1 percent, with an average of 17.4 percent. The protein content was relatively high during these years because of the prevalence of white clover (Figure 3.)

The percentage of crude protein in the forage during the years 1937 to 1941 is given in Table 4. The relatively high values obtained in 1937 undoubtedly are due largely to a carry-over of the nitrogen fixed by the white clover in the preceding years. Since there was almost no clover from 1937 to the spring of 1939, the protein content of the forage was

TABLE 4—*Crude-protein Content of Air-dry Herbage* (1937 to 1941)

Plot no.	Treatment*	Percentage of protein 1937	1938	1939	1940	1941	Av.
2	Check	12.6	8.5	8.6	9.2	9.6	9.7
6		13.9	9.1	9.3	10.7	11.4	10.9
1	P-L	14.5	10.1	13.6	15.0	15.1	13.7
5		14.4	10.0	11.0	14.4	13.2	12.6
3	P-K-L	15.6	10.4	12.7	15.6	14.1	13.7
7		14.6	10.9	13.5	15.1	14.2	13.7
4	N-P-K-L	16.0	12.7	13.9	14.1	14.9	14.3
8		15.2	11.7	14.6	15.0	15.1	14.3

*See Figure 1 for explanation of treatments.

low during 1938 and 1939. With a rise in the percentage of clover which began during the last part of 1939 and continued through 1940 and 1941, the protein content was markedly increased in the last two years of the experiment.

The high percentage of weeds and poor native grasses in the forage from the untreated pastures, in addition to the low content of white clover, undoubtedly accounts for the low average yields of protein on these pastures. Nitrogen, in addition to mineral fertilizers, did not materially increase the protein in the years when clover was present. However, when clover was absent, the use of nitrogen helped to maintain the protein content; as a result the average annual yields of protein were somewhat higher on the N-P-K-L pastures.

The average phosphorus, calcium, and potassium content of the air-dry herbage for the two years 1940 and 1941 are given in Table 5. From these data it is evident that the forage from the limed and fertilized pastures was still much higher in calcium, phosphorus, and potassium than that from the untreated pastures, even though 7 years had elapsed since the last application of mineral fertilizer. On the untreated pastures the forage contained an average of 0.64 percent calcium, 0.23 percent phosphorus, and 1.20 percent potassium. On the various treated pastures the use of lime and fertilizer increased the calcium content from 41 to 80 percent, the phosphorus from 30 to 57 percent, and the potassium from 11 to 48 percent over the average of the check plots.

TABLE 5—*Average Phosphorus, Calcium, and Potassium Content of Air-dry Herbage During the Years* 1940 *and* 1941

Plot no.	Treatment*	Calcium	Phosphorus	Potassium
		(percent)	*(percent)*	*(percent)*
2	Check	0.59	0.21	1.21
6		0.70	0.25	1.19
1	P-L	1.13	0.35	1.78
5		0.93	0.36	1.33
3	P-K-L	1.06	0.30	1.56
7		1.15	0.34	1.78
4	N-P-K-L	0.90	0.33	1.46
8		1.06	0.33	1.64

*See Figure 1 for explanation of treatments.

EFFECT OF LIME AND FERTILIZER ON YIELDS

The data obtained allow for calculation of yield of pastures in a number of ways. Since any method used is subject to some error, results by several methods are given together with a discussion of some of the limitations of the methods.

Days of Grazing

Records were kept of the number of animals on the pastures at all times. It is possible therefore to express the results in terms of days of grazing obtained per acre. These results for the dairy heifers are given in Table 6. They show a significant increase in days of grazing obtained as a result of treatment. In terms of days of grazing, the increase over the average of the check plots varied from 21.9 days for the poorest P-L plot to 83.7 days for the best N-P-K-L pasture. Expressed as percentage increase, the range was from 33.6 percent to 128.4 percent for the same plots. Considerable seasonal variation is evident, the highest values being obtained in 1933 and the lowest in 1936.

An attempt was made to keep each pasture uniformly stocked with animals of the same age and size. However, since the animals used varied in weight from approximately 500 to 1000 lbs., there was some variation in average size of animals on the various pastures. Likewise, it was difficult to maintain uniform grazing. As a result the average figures do not give a complete picture of yields. However, as shown later they do give a good indication of response to the various treatments.

Gains in Weight

Weighings were made at monthly intervals and whenever stock were added to or removed from pastures. From these the average gain in weight per acre may be calculated as given in Table 7. These show a range of from 98.1 lbs. on check pasture 2 to 255.2 lbs. on fertilized pasture 4. Increases over the average of the check plots vary from 34.1 lbs. on pasture 5 to 149.3 lbs. on pasture 4. Corresponding percentage increases vary from 32.2 to 141.0 on the same pastures. These show a decidedly greater gain in total weight of animals on the treated pastures. This was primarily the result of the larger number of animals pastured on the treated plots.

In evaluating pastures on basis of gain in weight it should be recognized that maintenance requirements must be met before any gains in weight take place. The amount required depends in part on the size of the animal. Therefore differences in size previously suggested would lead to some error in evaluation of treatment when using gain in weight as the only criterion.

Throughout the experiment the number of animals on each pasture was adjusted so as to consume most of the available forage and yet maintain satisfactory gains. It is known that differences in the nutritive value of forage may be reflected in daily gains. However, as shown in Table 8, the rate of gain in this experiment was not greatly affected by the various treatments.

TABLE 6—*Days of Grazing per Acre Obtained by Dairy Heifers*

Plot no.	Treatment*	1933	1934	1935	1936	1937	1938	1939	1940	1941	Average	Percentage increase
2	Check	[illegible]	63.9	65.5	39.6	70.9	[illegible]	62.4	55.0	57.3	63.5	
6	Check	88.0	66.5	92.8	32.8	78.2	54.7	63.0	56.8	69.2	66.9	
1	P-L	157.0	100.2	119.7	61.8	118.0	114.7	135.5	144.9	128.0	120.0	84.0
5	P-L	111.0	78.5	90.7	46.0	90.3	76.4	99.3	88.5	103.7	87.1	33.6
3	P-K-L	167.2	139.1	181.2	83.5	161.2	115.7	144.2	139.3	121.0	139.2	113.5
7	P-K-L	135.9	126.3	124.4	68.2	124.2	101.9	130.0	137.1	113.5	117.9	80.8
4	N-P-K-L	207.2	138.9	181.1	87.2	160.0	126.1	157.7	148.8	133.2	148.9	128.4
8	N-P-K-L	202.3	127.7	146.8	85.8	157.8	[illegible]	159.5	146.8	124.5	143.0	119.3

*See Figure 1 for explanation of treatments.

TABLE 7—*Heifer Gains in Pounds per Acre Obtained from Each Pasture*

Plot no.	Treatment*	1933	1934	1935	1936	1937	1938	1939	1940	1941	Average	Percentage increase
2	Check	114.6	137.0	96.0	104.6	78.0	89.6	86.4	65.3	81.1	98.1	
6	Check	170.2	111.2	134.0	72.4	145.8	90.5	91.6	73.0	134.8	113.7	
1	P-L	201.8	199.2	270.2	164.9	242.7	158.9	169.8	205.4	193.6	200.7	89.5
5	P-L	159.9	146.9	141.5	120.8	152.4	126.8	151.5	130.0	130.4	140.0	32.2
3	P-K-L	232.1	320.2	318.1	220.1	257.0	217.8	199.6	197.9	214.5	241.9	128.4
7	P-K-L	223.2	246.0	237.7	170.4	215.4	195.1	176.6	155.5	152.2	196.9	85.9
4	N-P-K-L	309.9	270.5	371.4	222.6	296.2	215.3	221.3	177.4	212.3	255.2	141.0
8	N-P-K-L	246.3	232.8	290.0	235.1	242.7	226.0	203.7	227.5	153.3	228.6	115.9

*See Figure 1 for explanation of treatments.

TABLE 8—*Effect of Lime and Fertilizer on Average Daily Gains per Animal* (1932-1941)

	Check plot		P-L plot		P-K-L plot		N-P-K-L plot	
	2	6	1	5	3	7	4	8
Daily gains per animal (pounds)	1.54	1.70	1.68	1.61	1.74	1.67	1.71	1.60

Although the untreated pastures were much higher in weeds and poor native grasses and were able to carry fewer animals than the limed and fertilized pastures, the animals which they did support were able to make equally rapid gains. It was observed during the study that on the untreated pastures the stock did most of their grazing on small areas within those pastures which were highest in desirable grasses. Much of the poor vegetation, particularly broomsedge and weeds, went untouched. Undoubtedly this selective grazing was an important factor in maintaining the daily gains on these pastures. On the treated pastures there probably was not enough difference in nutritive value to reflect differences between fertilizer treatments.

Total Digestible Nutrients

By utilizing the information on days of grazing, gains in weight, and requirements for maintenance, it is possible to calculate the amount of total digestible nutrients which the animals secured from the various pastures. These values, calculated as previously indicated, are given in Table 9. Because of the variations between duplicate pastures the yields are given for individual plots.

There was considerable variation in the yields of all pastures during the different years. The highest yields were obtained during the first four years of the experiment (1932 to 1935). This would be expected, since the lime and mineral fertilizers were applied in 1931 and 1933. Furthermore, white clover was most plentiful in those years.

As previously indicated, the annual yields of the pasture were greatly affected by moisture conditions. Dry weather depressed the yields in 1932 and 1934, whereas with favorable rainfall the maximum yields were obtained in 1933 and 1935. The most severe drought occurred in 1936, and this resulted in the lowest yields obtained during the 10 years of the study. The rainfall from 1937 to 1941 affected distribution of yield, but total yields show no great variations between years.

The data in Table 9 show that the use of lime and fertilizer was very effective in increasing the yield of total digestible nutrients (T.D.N.) in all years. It is indicated, however, that considerable variation in response existed on the two replications within each treatment. For example, the yield on one of the P-L pastures was always much greater than on the other. Likewise, except for the first year, one of the P-K-L pastures always gave higher yields than the other. On the two N-P-K-L pastures the difference in yield was small; one pasture did not consist-

ently yield more than the other. Some of this variation between replicates may have been due to grazing management, but it is believed to be largely the result of differences in original soil fertility and other soil factors. Probably to evaluate the response from the various fertilizers, this pasture variation must be carefully considered.

The average annual yields per acre of T.D.N. obtained from each pasture during the 10-year period 1932 to 1941 and the average percentage increase from the lime and fertilizer treatments are also given in Table 9.

The untreated pastures produced an average annual yield of 693 lbs. T.D.N. The use of lime and superphosphate increased the yield 27.7 percent on one pasture and 76.9 percent on the other. On the two pastures which received potash in addition to lime and superphosphate, the yield of T.D.N. was increased 78.8 percent and 108.9 percent. The use of lime and complete fertilizer increased the yield 124.7 percent and 112.0 percent, respectively, on the two pastures.

Standard Cow Days and Carrying Capacity

In Table 10 the average annual T.D.N. yield of each pasture for the 10-year period has been converted to standard cow days per acre and to equivalent carrying capacity in acres per cow. It has been found that a 1200-lb. cow producing 20 lbs. of 4-percent milk daily requires approximately 16 lbs. of T.D.N. for maintenance and milk production (5). Thus the number of standard cow days per acre is approximately the number of days on which each acre of pasture will support an average-producing dairy cow. The carrying capacity represents the number of acres of pasture required to support a similar cow during an average grazing season of 180 days.

The data in Table 10 show that the number of standard cow days per acre increased from 41.8 days on the poorest untreated pasture to 97.3 days on the best N-P-K-L pasture. The number of acres required to carry a cow during the grazing season on these same pastures varied from 4.3 acres to 1.8 acres.

TABLE 10—*Average Standard Cow Days per Acre and Equivalent Carrying Capacity in Acres per Cow* (1932 to 1941)

Plot no.	Treatment*	Standard cow day per acre†	Carrying capacity acres per cow‡
2	Check	41.8	4.3
6	Check	44.8	4.0
1	P-L	76.6	2.3
5	P-L	55.3	3.2
3	P-K-L	90.5	2.0
7	P-K-L	77.4	2.3
4	N-P-K-L	97.3	1.8
8	N-P-K-L	91.8	2.0

*See Figure 1 for explanation of treatments.
†Standard cow days per acre $= \frac{\text{T.D.N. per acre.}}{16}$
‡Acres required to support an average-producing dairy cow for 180 days.

TABLE 9—*Yield of Total Digestible Nutrients Obtained from Each Pasture*

Plot no.	Treatment*	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	Average	Percentage increase
		Pounds per acre											
2	Check	892	1025	703	664	479	625	524	628	546	589	670	
6	Check	853	986	704	931	358	811	585	629	541	776	717	
1	P-L	1109	1561	1099	1398	746	1287	1100	1260	1399	1304	1226	76.9
5	P-L	876	1128	827	893	526	930	763	1016	885	1008	885	27.7
3	P-K-L	1376	1678	1604	1981	932	1558	1240	1434	1361	1318	1448	108.9
7	P-K-L	1565	1436	1366	1471	686	1208	1069	1242	1214	1135	1239	78.8
4	N-P-K-L	1639	2120	1558	2089	931	1657	1317	1510	1410	1344	1557	124.7
8	N-P-K-L	1700	1907	1390	1703	924	1542	1401	1478	1482	1167	1169	112.0

*See Figure 1 for explanation of treatments.

TABLE 11—*Digestible Nutrients Obtained from Grazing Compared with Equivalent Alfalfa Hay Nutrients and Their Value Above Fertilizer Costs; Value of Fertilizer Treatments**

Plot no.	Fertilizer treatment	Total digestible nutrients	Alfalfa hay equivalent	Value of hay at $20 per ton	Cost of fertilizer and application	Value of hay equiv. less cost of fertilizer treatments	Increased value due to fertilizer treatment per acre per year
			(pounds)				
2	Check	670	1332	$13.32	...	$13.32	...
6	Check	717	1425	14.25	...	14.25	...
Av.		693	1378	13.78	...	13.78	...
1	L-P	1226	2437	24.37	1.84	22.53	8.75
5	L-P	885	1759	17.59	1.84	15.75	1.98
3	L-P-K	1448	2879	28.79	2.32	26.47	12.69
7	L-P-K	1239	2463	24.63	2.32	22.31	8.63
4	L-P-K-N	1557	3095	30.95	6.36	24.59	10.81
8	L-P-K-N	1469	2920	29.20	6.36	22.84	9.06

*Average of 10 years on an acre basis.

Distribution of Yield

The data presented thus far have dealt only with the total seasonal production of the pastures. It is also highly important to observe the effect of lime and fertilizer on the production of the pastures during each month of the grazing season. Since the cattle were weighed at approximately monthly intervals, it is possible to calculate the average monthly yield of T.D.N during the 10-year period. These data are given in Figure 4.

The highest average monthly yields during the 10-year period were obtained in the early part of the grazing season. It is encouraging, however, to note that a substantial increase in yield from the use of lime and fertilizer occurred during every month of the grazing season. There was a slight tendency for the percentage increases in yield to decline from May to July and then to rise again from August through September. Also it appears that nitrogen had little effect in September and October.

The percentage of total yield by months, given in Figure 5, shows that the percentage of the total annual yield which occurred in each month is about the same regardless of treatment. This indicates that the increase in yield due to the use of lime and fertilizer is the result of generally uniform increases throughout the entire grazing season. Nitrogen, as well as mineral fertilizers, had little effect on the distribution of the yield.

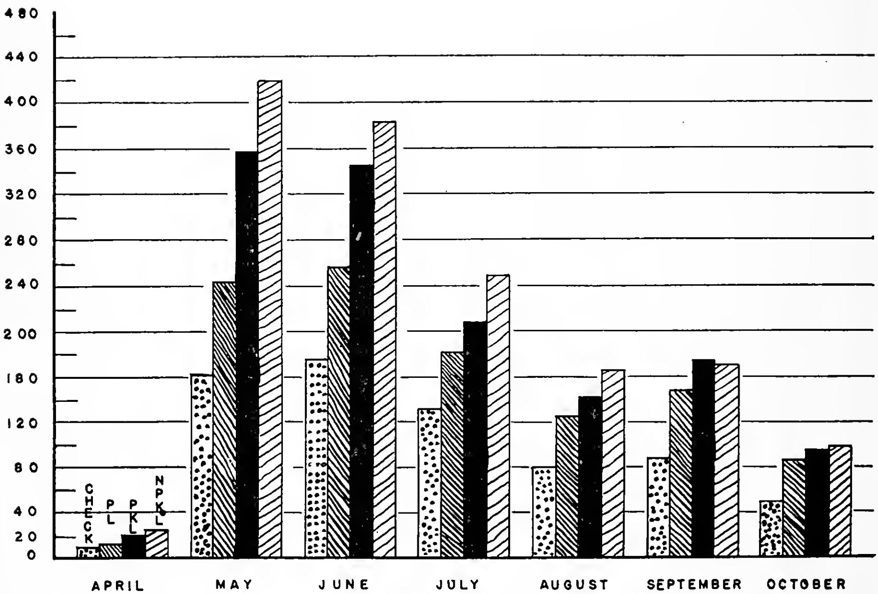

FIGURE 4—The Average Monthly Yield of T. D. N. (1932 to 1941) Each value is the average of two replications. (See Fig. 1 for explanation of treatments.)

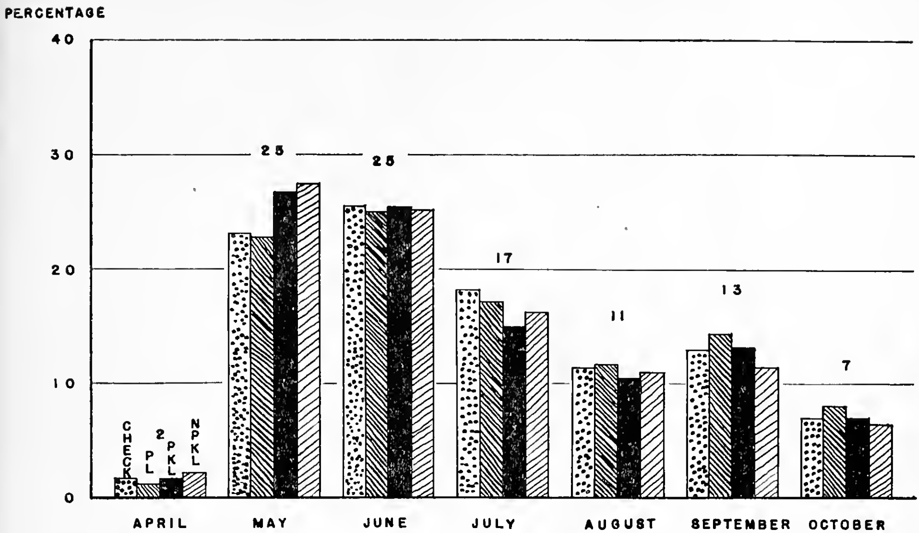

FIGURE 5—The Percentage of the Total Yield of T. D. N. Which Occurred in Each Month of the Grazing Season (1932 to 1941)
Each treatment is the average of two replications. (See Fig. 1 for explanation of treatments.)

The data in Figure 5 further emphasize the fact that over the 10-year period the greatest yield of the pastures occurred in the early part of the grazing season. It is shown that approximately 50 percent of the total yield was obtained in May and June. Of the remaining yield, 2 percent was obtained in April, 17 percent in July, 11 percent in August, 13 percent in September, and 7 percent in October. This variation in the monthly distribution of the yield is the result of climatic conditions, particularly moisture, and of the fact that bluegrass has a natural tendency to make its maximum production early in the season.

VALUE OF PASTURE FERTILIZATION

The value of T.D.N. may be calculated by converting these into hay equivalent. Such a comparison is given in Table 11, using alfalfa hay at $20 per ton as a basis. The hay equivalent figures were computed by allowing 50.3 lbs of T.D.N. for 100 lbs. of alfalfa hay as given by Morrison (*6*). The value of $20 per ton for alfalfa hay was considered a fair average value in 1942. The prices charged for lime and fertilizer were the market prices in the same year. These were distributed over the 10-year period. The cost of application was figured at 50 cents per acre for each application.

The annual net profit per acre per year from the use of lime and fertilizer varied from $1.98 per acre per year for pasture 5 to $12.69 for pasture 3. In all pastures the value of the increased production was greater than the cost of purchasing and applying materials. Because of variations between pastures, it is not possible to place much emphasis

on the differences in values obtained. However, the results indicate that there are conditions where potash may be profitably used in addition to the commonly recommended lime and superphosphate. They also show that nitrogen applications gave sufficient increase to pay for the application under the conditions of the experiment.

DISCUSSION

The data clearly indicate that treatment of these pastures with lime and fertilizer has had a marked effect on carrying capacity of the pasture over the 10-year period. They also show a considerable residual effect of certain of the treatments, particularly lime and superphosphate.

Since there were no pastures receiving only lime or superphosphate treatments, it is not possible to evaluate the individual effects of these on yields. However, the acidity of the soil is such that it would be reasonable to expect a considerable benefit from liming. Results of small plot experiments clipped with a lawn mower in this area gave increased yields of 16 percent for lime alone over the check and 14 percent for lime and phosphate over phosphate alone for 1932 and 1933 (*8*). The plant analysis given in Table 5 shows that liming increased the calcium content of the herbage.

Some indication of the effect of phosphate fertilizers may likewise be gathered from clipped plots in the area. In 1932 and 1933 these showed increases of 33 percent for superphosphate over the check plots and 30 percent for phosphate and lime over the limed plots (*8*). The plant analysis data given also show a considerable effect of treatment on the phosphate content of the herbage. Although these data cannot be taken as a measure of the relative effects of lime and superphosphate over the entire pasture area, they do indicate that both were necessary for greatest increases in yield, since the combined effect of lime and phosphate increased the yield over untreated plots by 51 percent.

Attention has been called to the relatively poor response to lime and superphosphate on pasture 5. The plant-analysis data indicate that the herbage is lower in potash than that of any of the other treatment plots. Soil analysis from the area also shows a low content of exchangeable potash in comparison to the other plots. From these data it would appear that the reason for low yields is related to potash deficiency on this area. This is quite different from plot 1, which, although it did not receive potash fertilizer, has the highest content of exchangeable potash in the soil (Table 2), and the potash content of the herbage is as high as the highest of the potash-treated plots. These differences are undoubtedly associated with soil variation. The small plot experiment (*8*) which showed little response to potash fertilizer was located in plot 2 and immediately adjacent to plot 1. It probably represents a true picture of potash response on that section of the experimental area. Other data from Monongahela soils indicate that many of these are low in exchangeable potash and that a response to potash fertilizer would usually be expected on this soil series.

The yields have been expressed in three ways: *i. e.*, days of grazing per acre, pounds of gain in weight per acre, and total digestible nutrients

per acre. As previously indicated, these measurements include some of the same factors, but it is of interest to bring the three factors together to show how closely the three ways of expressing relative yields agree. This is shown in Table 12, in which the average of the untreated plots is taken as 100.

TABLE 12—*Relative Response as Measured by Days of Grazing, Gain in Weight, and Total Digestible Nutrients*

Plot no.	Treatment	Pasture days	Gains in weight	T.D.N.
2 & 6	Check	100	100	100
1	P-L	184.0	189.5	176.8
5	P-L	133.6	132.2	127.6
3	P-K-L	213.5	228.4	208.8
7	P-K-L	180.8	185.9	178.7
4	N-P-K-L	228.4	241.0	224.5
8	N-P-K-L	219.3	215.9	211.8

These data indicate that, by careful grazing management, one may get a good measure of relative yields by any one of the three methods of calculation. Since days of grazing or pasture days are relatively easy to measure, one may, by careful selection of animals used and proper grazing management, get a good estimate of relative yield of pasture by this method. These may then be converted into approximate carrying capacity merely by dividing the number of days in the pasture season by the number of days the animals were kept on pasture.

The calculation of profits from fertilizer on the basis of alfalfa-hay equivalent at $20 per ton, which showed that all treatments were profitable during the 10-year period, may appear to be somewhat high. However, no credit was given to further residual effect, which is still quite marked. Furthermore, in the case of producing dairy cattle, quality of feed is of even greater importance than for dairy heifers or for other types of livestock. The higher protein and mineral content of the herbage on the treated areas would also influence the value of the herbage.

SUMMARY AND CONCLUSION

Results are reported for 10 years' tests of carrying capacity of eight pastures on Monongahela silt loam grazed with Ayrshire cows and heifers. The treatments included (1) untreated or check pasture, (2) lime and superphosphate, (a) lime, superphosphate, and potash, and (4) lime, superphosphate, potash, and nitrogen. Each treatment was made in duplicate. Results reported include pasture days, gains in weight, total digestible nutrients, stand of grasses, and chemical composition of clipped herbage.

The results show a marked increase in yield for all treated pastures, the increase in T. D. N. being 27.7 and 76.9 percent for the P-L pastures, 78.8 and 100.8 percent for the P-N-L pastures, and 112.0 and 124.7 percent for the N-P-K-L pastures. The small number of plots makes it impossible to draw positive conclusions regarding the value of the various treatments. Certain conclusions, however, are clearly indicated:

1. Lime and superphosphate gave profitable increases in yield on both plots. Results from one pasture were much better than from the other. Chemical analyses of the soil and herbage indicate that on one pasture this difference was the result of potash deficiency.

2. Potash, in addition to lime and superphosphate, gave profitable increases in yield on this area. The increase was relatively small when the potash-treated pastures were compared to the best P-L plot. Other soil analyses from Monongahela soils indicate a low content of available potash, and it is believed that pastures will frequently show response to potash on this soil.

3. Nitrogen fertilizer increased yields, but the increase was no more than enough to pay for the cost of applying the fertilizer. When acreage is limited and lime and fertilizer have previously been applied, it may give more profitable returns.

4. Liming and fertilizing increased the amount of clover and bluegrass in all pastures.

5. Analyses of the herbage showed marked increases in mineral and protein content as a result of liming and fertilization.

6. Soil analyses show a considerable residual effect in 1942 of the lime and superphosphate applied in 1931 and 1933. The treated pastures also showed a higher organic-matter content at the close of the experiment.

7. There is good agreement between increases in yields as measured by days of grazing obtained, gain in weight, and yield of total digestible nutrients.

LITERATURE CITED

(1) Association of Official Agricultural Chemists. Official and tentative methods of analysis of the Association of Official Agricultural Chemists. 4th ed., 710 pp. Washington, D. C. 1935.

(2) Brown, D. S., Robinson, R. R., and Browning, G. M. Determination of small amounts of potassium. Ind. and Eng. Chem., anal. ed., *10*: 652-654. 1938.

(3) Eckles, C. H., and Gullickson, T. W. Nutrient requirements for normal growth of dairy cattle. Jour. Agr. Res. *42*: 603-616. 1931.

(4) Fiske, C. H., and Subbarow, Y. The colorimetric determinations of phosphorus. Jour. Biol. Chem. *66*: 375-400. 1925.

(5) Knott, J. C., Hodgson, R. E., and Ellington, E. V. Methods of measuring pasture yields with dairy cattle. Wash. Agr. Exp. Station Bul. 295. 1934.

(6) Morrison, F. B. Feeds and Feeding, a handbook for the student and stockman. 20th ed., 1050 pp. Morrison Pub. Co., Ithaca, N. Y. 1936.

(7) Pierre, W. H., Longwell, J. H., Robinson, R. R., Browning, G. M., McKeever, Ivan, and Copple, R. F. West Virginia pastures: Type of vegetation, carrying capacity, and soil properties. W. Va. Agr. Exp. Sta. Bul. 280. 1937.

(8) Robinson, R. R., and Pierre, W. H. Response of permanent pastures to lime and fertilizers (1930 to 1936). W. Va. Agr. Exp. Sta. Bul. 289. 1938.

(9) Robinson, R. R., Pierre, W. H., and Ackerman, R. A. A comparison of grazing and clipping for determining the response of permanent pastures to fertilization. Jour. Amer. Soc. Agron. *29*: 349-358. 1937.

(10) Truog, Emil. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron. *22*: 874-882. 1930.